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SCUDERI SPLIT CYCLE ENGINE: REVOLUTIONARY TECHNOLOGY & EVOLUTIONARY DESIGN REVIEW

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ABSTRACT

The IC engine has seen numerous revolutionary and evolutionary modifications in technology and design over the past few decades. The sole motto behind the modifications was to increase the overall efficiency of the IC Engine including volumetric and thermal efficiency. Recently few benchmarking technologies like the CRDI, MPFI, HCCI, etc. in the Otto cycle and Diesel cycle engines have created an enormous revolution in the automobile industry. In spite of these technological and design advances, the efficiencies are not being more than a particular limit. However, the concept of split cycle engines has drastically increased the overall performance in all respect. The split cycle concept basically separates the four strokes of the conventional cycle. The Scuderi engine one of the best-in-class engine designs based on the split cycle concept. The Scuderi engine works on the split cycle and gives higher efficiency than the previous split cycle engines resulting overall high performance. It also eliminates the problems faced by previous engines based on the split cycle in terms of breathing (volumetric efficiency) and thermal efficiency. This paper throws light on the greater volumetric, thermal and overall efficiency key points related to the Scuderi Engines.

KEYWORDS: Split Cycle, Scuderi Engine, Volumetric Efficiency, Thermal Efficiency.

INTRODUCTION

The Scuderi engine works based on the split cycle. A split cycle engine is an IC engine that separates the four strokes of Intake, Compression, Power and Exhaust. These strokes separation is achieved by using two separate but paired cylinders of the Scuderi engine are named as the Compression Cylinder (i.e. First Cylinder) and the Power Cylinder (i.e. Second Cylinder). The sucked atmospheric air is compressed into the Compression Cylinder and then it is sent to the Power Cylinder. The system through which the compressed air is transferred to the Power Cylinder is known as Crossover Passage. The compressed air is then mixed with injected fuel and the combustion takes places in the Power Cylinder.

HISTORY

The split cycle engines appeared as early as 1914. Various split cycle configurations with different specifications were designed but they failed to match the efficiency of the conventional IC Engines. This was because of the two predominant causes i.e. Breathing (Volumetric Efficiency) and Low Thermal Efficiency.

The Scuderi engine was invented by Carmelo J. Scuderi. The Scuderi engine was formally known as Scuderi Split Cycle Internal Combustion Engine. Scuderi Group is an engineering and licensing company situated in West Springfield, Massachusetts and founded by Carmelo Scuderi following own generations. The first working prototype engine after testing was officially revealed by the Scuderi Group to the public in the year 2009. The Scuderi Group had around more than 476 patent applications worldwide as of August 2011 and more than 154 applications as patens have issued in more than 50 countries.

WORKING

The Scuderi engine is a split cycle internal combustion engine. It has two separate but paired cylinders for performing the conventional four strokes of Intake, Compression, Power and Exhaust. The first cylinder, generally known as the Compression Cylinder, used for taking the air inside and compressing it. The compressed air is then sent to the second cylinder through a passage known as the Crossover Passage. The second cylinder, generally known as the Power Cylinder, used for Power and Exhaust Strokes [5].

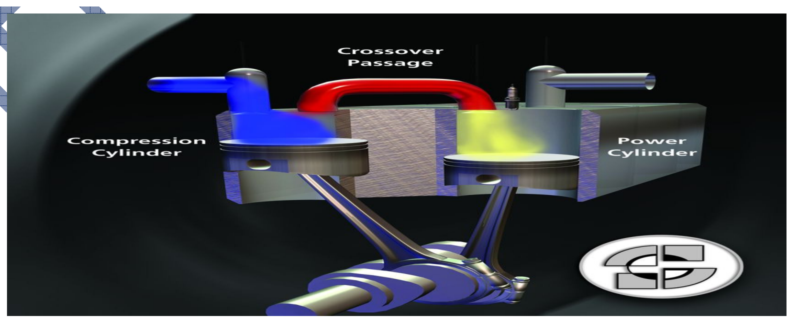

Fig. 3 Scuderi Split Cycle Engine [6]

Compression Curve: The compression stroke is negative work, or energy that the engine expends to do work on the gas. When the piston is at the Top Dead Center (TDC) during the intake stroke, the inlet valve of the compression cylinder opens allowing the atmospheric air to enter into the cylinder at atmospheric pressure (low pressure). The volume in the cylinder starts increasing as the piston starts travelling from its TDC to BDC (Bottom Dead Center).

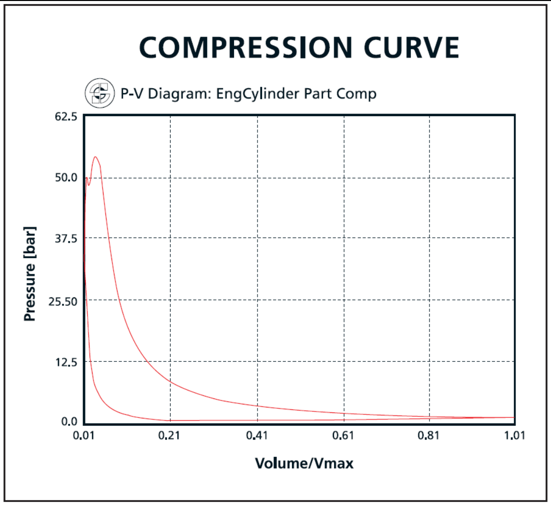

Fig. 3.1 P-V Curve for Compression Cylinder [6]

At BDC, the inlet valve closes resulting low pressure air trapped inside compression cylinder.
Then the piston starts its travel from the BDC to TDC, the trapped air starts compressing as the volume in the cylinder decreases and there is a pressure rise in the cylinder. When the pressure in the compression cylinder reaches high enough (around 50 bar), the crossover passage inlet valve opens and the pressurized air is then transferred to the crossover passage. When the piston reaches TDC, outlet valve of crossover passage closes and inlet valve of compression cylinder opens and the pressure instantaneously reduces to atmospheric pressure. As the pressure is now atmospheric, the above process repeats as graphically represented on Fig. 3.1 P-V Curve for Compression Cylinder.

Power Curve: The power stroke is positive work, or energy that the expanding gases of combustion perform on the engine to create mechanical work. When the piston in power cylinder is at TDC, the crossover outlet valve opens resulting high pressure air enters inside the power cylinder. Then power piston starts its travel from TDC to BDC, fuel is injected inside the power cylinder and combustion initiates after power piston has displaced by around 10° to 15° form the TDC [6].

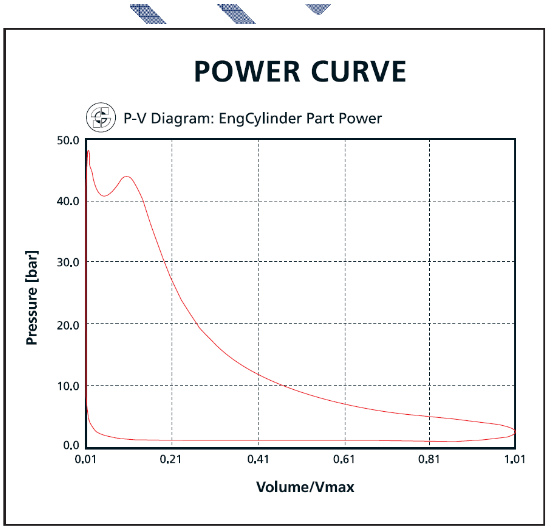

Fig. 3.2 P-V Curve for Power Cylinder [6]

Power stroke occurs for each revolution of crank shaft rather than per cycle. After this, the crossover passage outlet valve closes and the pressure in the power cylinder increases even though the volume is also increasing. The power cylinder travel from TDC to BDC continues and the volume is constantly increasing with the pressure starting to reduce. When power piston starts its return travel from BDC to TDC, outlet valve of power cylinder opens resulting to push the exhaust gases out of the system at atmospheric pressure. Power cylinder outlet valve is generally known as exhaust valve. When the piston reaches TDC, all the exhaust gases are expelled to the atmosphere and the above process repeats as graphically represented on Fig. 3.2 P-V Curve for Power Cylinder.

The areas inside the P-V curves reflect the amount of energy consumed and generated during each cycle. The net energy produced by the Scuderi Engine (its efficiency) is the difference between energy generated during the power stroke and the amount of energy consumed during the compression stroke.

REVOLUTIONARY TECHNOLOGY

The revolutionary feature of the Scuderi engine is the combination of a split cycle design with the combustion process of firing ATDC in power cylinder. The Scuderi split cycle engine improved the design and developed the components and supporting systems like crossover valves, crossover passage, fuel delivery system and power piston head design, ignition timing and valve lash controls etc. The Scuderi split cycle engine solves both the poor breathing (volumetric efficiency) and low thermal efficiency problems with two unique and patented concepts as unique valve design and Firing after Top Dead Center (ATDC), referred as revolutionary technology.

Unique Valve Design

The poor breathing problem was caused by high pressure charge of air trapped inside the compression cylinder due to clearance exists at TDC on the top of piston. This trapped high pressure charge of air needed to re-expand before another charge of air could be drawn into the compression cylinder, effectively reducing the engine capacity to pump the atmospheric air and resulting in poor volumetric efficiency.

Fig. 4.1 Unique Valve Design [6]

The Scuderi Engine is solved the poor breathing problem by reducing the clearance between the piston and the cylinder head to less than 1mm [6]. This design requires the use of outwardly opening valves that enable the piston to move extreme close to the cylinder head. This avoids interference of the valves with piston in compression cylinder. This effectively pushes almost complete charge of the compressed air from the compression cylinder into the crossover passage though crossover inlet valve. This design eliminates the breathing problems associated with previous split cycle engines resulting greater volumetric efficiency.

Firing After Top Dead Center (ATDC)

The thermal efficiency of previous split cycle engines has always been significantly worse than a conventional Otto cycle engine. The cause of low thermal efficiency is combustion initiates before top dead center (BTDC) like a conventional engine. In order to fire BTDC in a split cycle engine, the trapped charge of compressed air, in the crossover passage is allowed to expand into the power cylinder during the power piston is travelling from BDC to TDC. The work done on the compressed air in the compression cylinder is lost by releasing the pressure of the same in the power cylinder. The power piston then recompresses the expanded charge of compressed air in order to fire BTDC. The engine needs to perform the work done, to compress the same charge of air twice. In a conventional engine, the work of compression is done only once, resulting it achieves much better thermal efficiency.
The combustion initiates ATDC by using a combination of high pressure compressed air trapped in the crossover passage and high turbulence in the power cylinder of Scuderi split cycle engine. The compression cylinder and power cylinder in a Scuderi split cycle engine are independent from each other. The compression ratio in the compression cylinder is not limited by the combustion process. A compression ratio in the order of 75:1 is obtained, with pressure in the compression cylinder equal to that of a conventional engine during combustion. The pressure in the compression cylinder and the crossover passage reach more than 50 bar (725 psi) on naturally aspirated (NA) engine and more than 130 bar (1885 psi) on turbocharged (TC) engine [6]. This high pressure compressed air enters inside the power cylinder and creates massive turbulence. The turbulence is further enhanced by keeping the crossover outlet valve open as long as possible during combustion. The result is very rapid atomization of the air/fuel mixture, creating a fast flame speed or combustion rate faster than any previously obtained. The combination of high starting pressure and fast flame speed enables combustion to start between 11 and 15 degrees ATDC and end 23 degrees after ignition [6]. The result is a split cycle engine with better efficiency and greater performance than a conventional engine.

EVOLUTIONARY DESIGN

The evolution is the innovative design that derived from the unique concept of revolution technology used in the Scuderi split cycle Engine. Its evolution into the various configurations of naturally aspirated, turbocharged, air-hybrid and diesel designs, the Scuderi split cycle engine technology provides a simple but elegant solution to meet the engine demands for increased efficiency, improved power, downsizing and lower emissions.

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Scuderi Turbocharged Split Cycle Engine

The turbocharged version is the next development of the Scuderi split cycle engine. This version provides high torque, high speed, enormous power and smaller engines. The crossover passage provides an opportunity to cool the intake air after it is compressed in compression cylinder. The Scuderi split cycle engine has a very high resistance to pre-detonation (knock). This high resistance to knock potentially enables the Scuderi split cycle engine to boost or turbocharge to more than 2.5 bar absolute pressure. A conventional engine(s) typically can boost up to 1.5 bar absolute before pre-detonation occurs. The result is a significantly higher Brake Mean Effective Pressure (BMEP) and torque level. In fact, the torque level of the Scuderi split cycle Engine matches or exceeds most turbocharged diesel engines. However, a Scuderi split cycle Engine can potentially obtain rated speeds of up to 6000 rpm. The combination of diesel like torque levels matched with gasoline like speed levels would result in a power density higher than any conventional engine available today. The Scuderi split cycle Turbocharged Engine has a potential power rating at 6000 rpm of up to 135 hp per liter. The Scuderi engine enables the industry to drastically downsize its engines (reducing fuel consumption and CO_2 emissions) without compromising performance.

Scuderi Split Cycle Diesel Engine

The biggest advantage of the Scuderi split cycle engine for diesel applications is the reduction in emissions. The tougher emission standards that will begin in 2010 are causing the cost of diesel engines to dramatically increase while performance is being compromised. The Scuderi Engine's combustion process of firing ATDC has an unusual effect of reducing both soot and NOx.

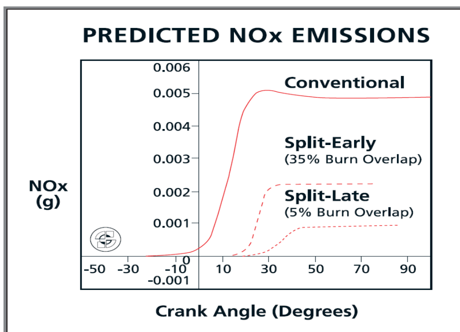

Fig. 5.2 Split Cycle Diesel Engine [6]

This results from the combustion cylinder in the Scuderi engine having a higher average temperature but at the same time a lower peak temperature than a conventional engine. The high average temperature, along with the high turbulence in the combustion process, is expected to reduce soot. However, lower peak temperatures resulting from combustion gases rapidly expanding when firing ATDC occurs, reduces NOx emissions by as much as 80 percent. The Scuderi split cycle engine offers a unique opportunity to reduce emissions to the new levels without the need for costly after treatment systems.

Air-Hybrid Design

The Scuderi split cycle engine is really a dedicated pneumatic compressor on one side and an engine on the other, it simply requires the addition of an air storage tank and some controls to convert it into a hybrid system that can capture and store energy lost during the normal operation of the engine. Since the turbocharged version of the Scuderi engine operates at 130 bar, it will be able to store a significant amount of energy in its air tank. There are various engine control strategies that can be employed to improve the overall reduction in fuel consumption. This includes engine shutoff at idle, air-only driving, off-loading of the compression cylinder and regenerative braking. The Scuderi Air-Hybrid provides a cost-effective hybrid solution that does not compromise performance.

ADVANTAGES

- The most important and key advantages of Scuderi split cycle revolutionary technology is the design flexibility of the engine.
- The features that are very difficult to implement or need additional equipments in a conventional engine design can be easily accomplished in Scuderi split cycle configuration. For example, supercharging can be added simply by increasing the diameter of the compression cylinder.
- Scuderi engines are compatible with additional devices like turbocharger used to recover energy from exhaust that in turn increases the overall efficiency.
- The Miller cycle can be achieved by simply increasing the length of the power cylinder.
- The piston friction can be reduced by offsetting the compression and power cylinders.
- The revolutionary technology reduces the NOx emissions by as much as 80 percent.
- Higher volumetric, thermal efficiencies and overall efficiency are achieved.

LIMITATIONS

- The Scuderi split cycle engine are still neither used in practice nor incorporated in all the vehicles.
- The power density is same as other gasoline engines due to compression cylinder.
- The additional number of cylinder increases the cost of the engine.
- The additional cylinder also adds up to increase in frictional losses.

CONCLUSION

From the above literature review, it can be concluded that the Split Cycle Engine is purely technological combination of pneumatic compressor and combustion chamber. The Scuderi Split Cycle Engine solves both the breathing (volumetric efficiency) and thermal efficiency problems by Unique Valve Design and Firing After Top Dead Center (ATDC) respectively as compared to the Previous Split Cycle Engines. The Scuderi Engine is more efficient than a conventional IC engines since an area inside P-V Curves is greater for Power Cylinder.

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